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The Design of Fiber Optical Sensor for the detection of Anthocyanin level in Blueberry

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Abstract: Blueberries' freshness, maturity, and nutritional worth can only be determined by their anthocyanin concentration. Known for its antioxidant qualities, anthocyanins are the pigments that give blueberries red, purple, and blue hues. Conventional techniques, such as spectrophotometry and high-performance liquid chromatography (HPLC), are very accurate yet costly, time-consuming, and destructive when used to measure anthocyanin quantities. Conversely, fiber optic sensors (FOS) use the absorption characteristics of visible light, namely in the 520-580 nm range, to provide a real-time, invasive option for anthocyanin detection. The main goal of this study is to simulate and create a fiber optic sensor to assess the amount of anthocyanins in crushed blueberries. A smashed Blueberry was used to simulate the transmission and absorption of light. This technique for quick and accurate anthocyanin measurement by simulating light propagation and absorption in crushed Blueberry samples and designing an ideal fiber optic setup. To construct the sensor, the right materials must be chosen, the system must be calibrated with different levels of anthocyanin concentrations, and FOS and laboratory testing must confirm its functionality. According to the results, fiber optic sensors have great promise for use in precision farming and quality control settings in the agricultural and food processing industries.
Keywords: Fiber Optic Sensor, Antioxidant, anthocyanin

I. INTRODUCTION

A. Background

Water-soluble pigments known as anthocyanins, which belong to the flavonoid group, provide fruits such as blueberries, grapes, and cherries with their vibrant blue, purple, and red colors. These compounds are fascinating because research has shown that they can enhance human health, particularly due to their antioxidant properties. These antioxidants have been linked to a reduced risk of cancer, heart disease, and other chronic illnesses[1]. Measuring anthocyanin concentration in blueberries, particularly crushed samples used in juice and food processing, is vital for ensuring quality control, evaluating ripeness, and determining nutritional value[2]. Traditional methods of anthocyanin quantification, such as HPLC and spectrophotometry, are precise but present several limitations. These techniques are destructive, require the destruction of the sample, are time-consuming, and involve complicated sample preparation[3][4]. Fiber optic sensors promise to detect antioxidant capacity that can be overcome by measuring precise levels like any other bioactive molecule[5]. By leveraging light absorption properties, specifically in the visible spectrum, FOS can provide destructive, rapid, and real-time measurements of bio-molecular extraction[6]. This study aims to develop a fiber optic sensor system that measures anthocyanin content in crushed blueberries[7]. Theoretical simulation of light propagation through crushed Blueberry samples, design fiber optic sensor optimized for anthocyanin detection[8], [9]. Experimental validation of the sensor's performance by comparing it to traditional methods. Exploration of the potential for real-time anthocyanin monitoring in industrial settings[10].

II. FIBER OPTIC SENSOR TECHNOLOGY

A. Fundamentals of Fiber Optic Sensing

A flexible optical fiber core, usually composed of plastic, is used by fiber optic sensors to transmit light. Total internal reflection ensures that light continues to travel through the optical fiber cable OFC [11]. The intensity of the light is altered by any interaction with external elements, such as crushed Blueberry samples. Certain visible spectrum wavelengths, particularly those between 520 and 580 nm, are absorbed by anthocyanins [12], [13]. By measuring the intensity of the light after it passes through or reflects off the Blueberry sample, one can determine the concentration of anthocyanins [10], [14].

B. Design of the Fiber Optic Sensor

The design of the fiber optic sensor system for anthocyanin detection focused on the following factors fiber material plastic was selected for the core material due to its superior transmission properties in the visible range. Plastic optical fibers (POF) were considered for their flexibility and cost-effectiveness but were ruled out due to lower sensitivity in the specific wavelength range [15][16]. Wavelength sensitivity the light source was filtered to emit light primarily in the 520-580 nm range, corresponding to the peak absorption of anthocyanins and change in output intensity[17]. Sensor configuration a reflection-based configuration was chosen, wherein light was transmitted through the fiber, interacted with the crushed sample, and the reflected light was measured. This setup allows for rapid, invasive measurements of anthocyanin concentration[18].

C. Sensor Process

Fig.1 shows that the core and cladding design FOS fiber optic cable (FOC) at the center of this FOC the cladding part was removed of FOC the remaining core is used as the sensing region of the FOS and a cladding layer was added to ensure efficient light confinement. A removed cladding was applied to the fiber to absorb light interaction with the crushed Blueberry sample and get output intensity[19]. This Blueberry sample becomes a cladding for increased or decreased light absorption within the fixed input wavelengths. In the detection system in this FOS, the fiber was coupled with a photodetector sensitive to the visible spectrum, capable of capturing intensity changes as light interacted with the anthocyanin-rich medium and photodetector output measured in millivolt[13][20][21].

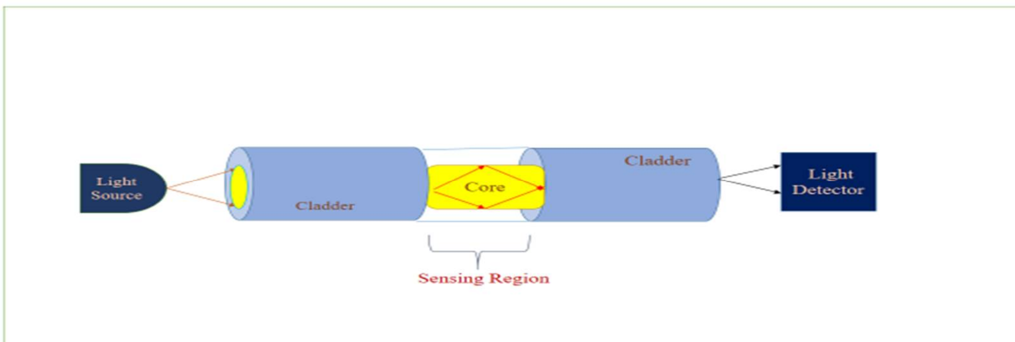

Fig.1 Schematic block diagram of intrinsic fiber optic sensor system

D. Fiber Optic Sensor for Anthocyanin Detection

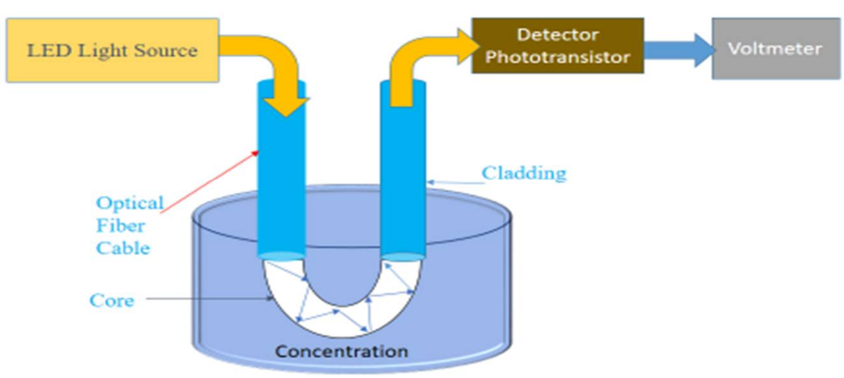

Fig.2 Block Diagram of U-Shaped Fiber Optic Sensor System

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Fig.2 shows the light propagation and absorption within complex media, the design related to some factors. Light source a visible light source emitting across the 400-700 nm spectrum was modeled, with a focus on the 520-580 nm range where anthocyanins absorb the most. Fiber Optic sensor specifications are the fiber core was designed from fiber with a cladding layer to ensure effective light propagation. Core diameter, numerical aperture, and refractive index were optimized to ensure maximum sensitivity in the target wavelength range. The crushed Blueberry sample was modeled as a homogenous medium with optical properties, including scattering, absorption coefficients, and refractive index values derived from experimental data on Blueberry anthocyanins [22], [23].

E. Sample Extraction Preparation

Destructive sampling was used to prepare Blueberry extracts to establish a dependable medium for sensor testing. To guarantee full antioxidant extraction, fresh blueberries were combined with a solvent made of distilled water and methanol. A clean extract appropriate for optical measurement was obtained by filtering the combination to get rid of pulp and other impurities. We produced and examined three samples. The concentrations of Blueberry extract and DPPH (2, 2-diphenyl-1-picrylhydrazyl) solution used to create Sample 1 (S1) were tested at 20%, 40%, 60%, 80%, and 100%. Sample 2 (S2) employed a DPPH solution with a standard concentration of 20 µg/ml Blueberry extract, also tested at 20%, 40%, 60%, 80%, and 100%. The solvent used in Sample 3 (S3) was distilled water with a DPPH solution of 20 µg/ml and the same range of concentrations[17], [24].

The FOS system was used to evaluate the antioxidant activity of each sample concentration. The following is how reaction ratios were standardized: Apply a homogeneous amount of antioxidant agent (AA) + DPPH (0.5 ml + 1.5 ml = 2 µg/ml) to methanol, distilled water, and DPPH solutions. The reference antioxidant was ascorbic acid, which had a standard concentration of 20 µg/ml. The Blueberry extracts were examined in two different ways: first, mixed with distilled water and DPPH solution at different concentrations, and second, mixed with methanol and DPPH solution at different concentrations. A thorough evaluation of antioxidant activity under various extraction and solvent conditions was made possible by this experimental setup[13], [19], [25], [26].

F. Standard Antioxidant Solution Calibration

Normal Antioxidant Solution Calibration As an antioxidant, ascorbic acid was first calibrated in the sensor using standard solutions with known concentrations. Then it was calibrated using the concentration found in blueberries. A calibration curve was created by recording the sensor's response (intensity and absorbance) for each concentration, which ranged in ratio with solvent from 1µg/ml to 2µg/ml[17].

III. DATA COLLECTION AND ANALYSIS

The FOS's output intensity and concentration ratio level were used to process the sensor's output. Accurate predictions of the anthocyanin antioxidant concentrations in the extracts are made using the sensor's reaction to the standard solutions. Data analysis compared sensor responses with known antioxidant levels of anthocyanins to confirm prediction accuracy. Information was gathered from multiple experiments to ensure reliability. The sensor's reaction to different antioxidant concentrations for green LED source and output photodetector responses was investigated using a 2ml/µ concentration ratio. The sensor's sensitivity, accuracy, and repeatability were evaluated using statistical analysis, and the result was expressed in millivolts[8], [14], [27], [28].

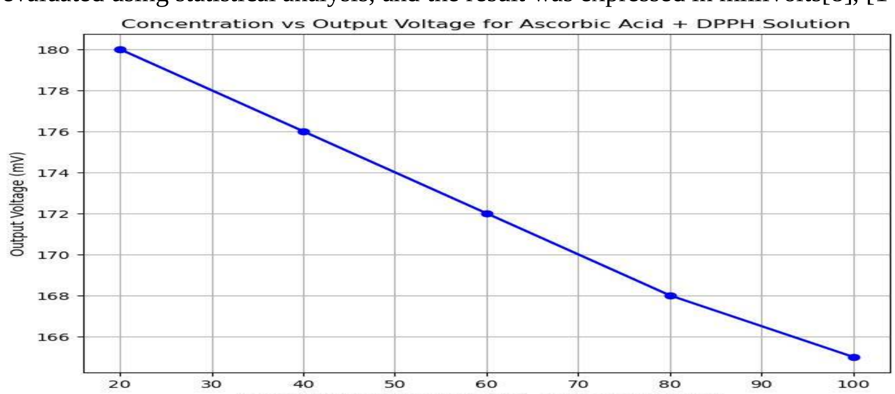

Fig. 3 Graph shows a concentration of ascorbic acid +DPPH versus output voltage in millivolt

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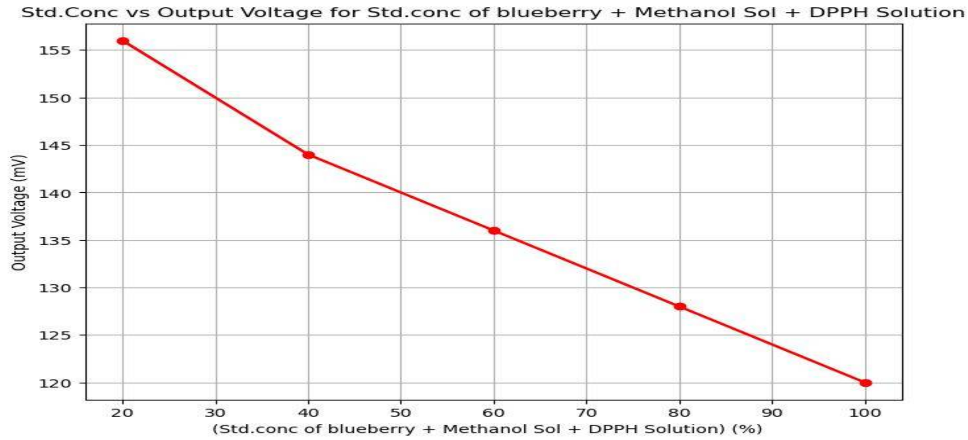

Fig. 4 Graph shows a concentration of Blueberry Conc + Methanol + DPPH versus output voltage in millivolt.

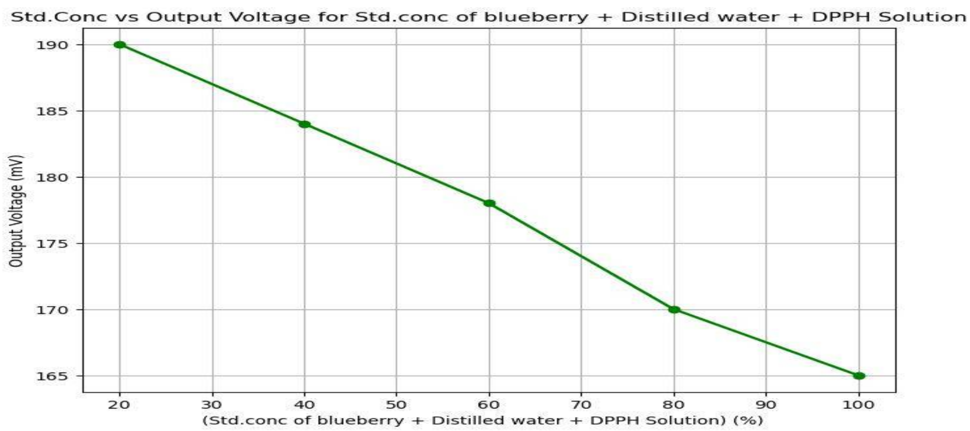

Fig. 5 Graph shows a concentration of Blueberry Conc. + Distilled Water + DPPH versus output voltage in millivolt.

IV. RESULTS

The design FOS showed a strong correlation between the anthocyanin content in the crushed blueberry sample and light absorption in the 520–580 nm region. The possibility of anthocyanin detection with fiber optics was confirmed by the considerable drop in transmitted light intensity as the anthocyanin content rose. Additionally, the design indicated that adjusting the light source to emit mostly within the anthocyanin absorption band could result in excellent detection. Crushed Blueberry samples with known anthocyanin concentrations were made and tested using both the fiber optic sensor and conventional spectrophotometry to verify the accuracy of the sensor. The sensor's ability to precisely quantify anthocyanin content in real time was confirmed by the data, which demonstrated a significant connection between the two approaches. To evaluate the sensor's viability for real-time anthocyanin monitoring in food processing environments, it was placed in a mock industrial scenario. The findings showed that the fiber optic sensor could assess anthocyanin levels continuously, enabling quick decision-making and quality management.

V. DISCUSSION

Compared to conventional anthocyanin measurement methods, fiber optic sensors provide several clear advantages. The sensor uses a destroyed blueberry sample, which enables real-time anthocyanin measurement. Fiber optic sensors yield data instantly, in contrast to spectrophotometry or HPLC, which need sample preparation and analysis time. Cost-Effectiveness. When used in agricultural and food processing applications, fiber optic sensors can drastically save operating costs. The sensor's performance may be impacted by changes in temperature, humidity, and sample. To increase sensor resilience in a variety of environmental circumstances, more investigation is needed. Assimilation into current systems it could be necessary to integrate fiber optic sensors with current monitoring devices and systems to adapt them for widespread use in industrial settings.

VI. CONCLUSION

A fiber optical sensor for identifying anthocyanin in blueberries was effectively developed and verified in this work. The sensor is a useful instrument for evaluating agricultural quality because of its sensitivity, precision, and destructive methodology. This research successfully demonstrated the potential of fiber optic sensors for measuring anthocyanin content in crushed Blueberry samples. By designing light propagation through anthocyanin-rich media and designing a. The fiber optic sensor that was created provides a novel and effective way to identify the concentration level of anthocyanins in blueberries. It is a useful tool for the food and agriculture industries, improving production processes and quality control due to its accuracy, mobility, and destructive nature.

VII. ACKNOWLEDGMENT

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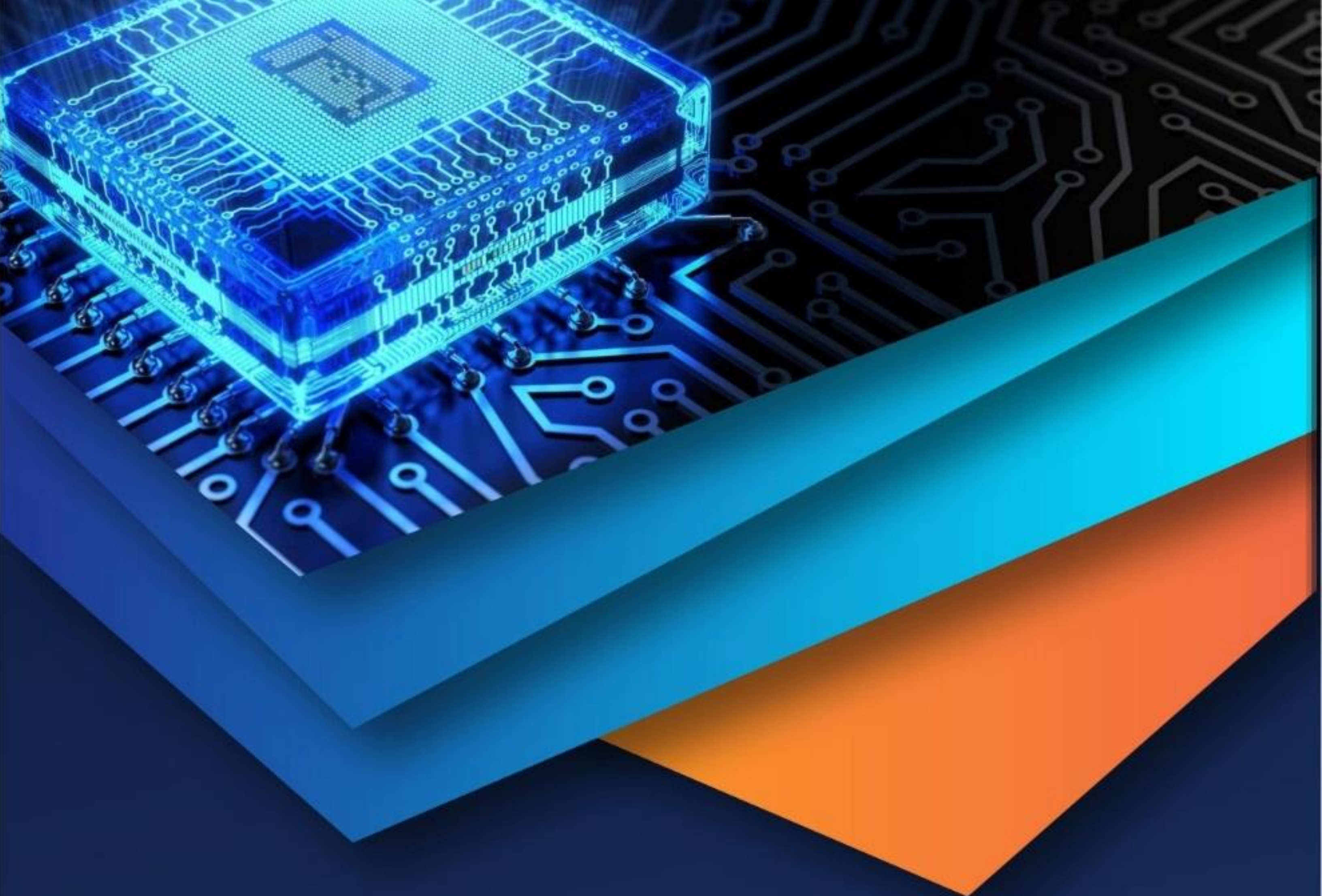

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